ISSN 2229-5518

# Implication of an Axial flow Compressor

**ABSTARCT:** The main objective in this thesis is to give encyclopedic on the axial flow compressor .Axial flow compressor is used to get the compressed pressurized air as an input the gas turbine. This thesis includes the performance parameters of axial flows such as energy exchange between the rotor and fluid compressor and variation of flow over a axial blade of the compressor. Here we discuss about the mass flow, rotational speed, number of stages, pressure ratio and which effect the efficiency of the axial compressor .Now we are going to deal with the effect of stalling and surge on the fluid flow and also deal with the compressor map by these parameter it useful in the design of Axial flow compressor .The work presented comprises of basic flow parameters and dimensions of parts, this makes the further design process quite simple and the results will be helpful to take further changes or improvement at the time of detailed design. By this thesis we know significances of axial flow compressor and why it is more efficiently used in turbojets nowadays when compare with other turbo machinery.

## INTRODUCTION:

Axial and centrifugal-type compressors typically fall into the compressors. know as a term 'rotodynamic compressor' typically

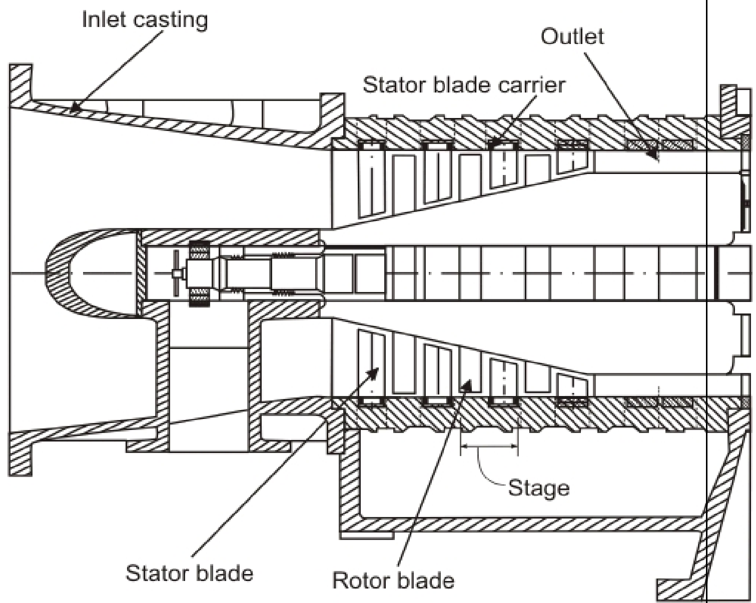
refers to a continuous-flow compressor, which uses rotating impellers in order to add velocity and pressure to the gas undergoing compression. Compared to positive displacement type compressors, dynamic compressors are typically smaller in size and create less vibration. An **axial compressor** is a machine that can continuously pressurize gases. (General Engineering) a device for compres sing a gas by accelerating it tangentially by means of bladed rotors, toincrease its kineti c energy, and then diffusing it through static vanes (stators), to increase its pressure.It is a rotating, airfoil-based compressor in which the gas or working fluid principally flows parallel to the axis of rotation. This differs from other rotating compressors such as centrifugal compressors, axi-centrifugal compressors and mixed-flow compressors where the fluid flow will include a "radial component" through the compressor.

The energy level of the fluid increases as it flows through the compressor due to the action of the rotor blades which exert a torque on the fluid. The stationary blades slow the fluid, converting the circumferential component of flow into pressure. Compressors are typically driven an electric motor or a steam or a gas turbine.[1]

ISSN 2229-5518

# Machinery and operation (mechanism)

The basic components of an axial flow compressor are a rotor and stator, the former carrying the moving blades and the latter the stationary rows of blades. The stationary blades convert the kinetic energy of the fluid into pressure energy, and also redirect the flow into an angle suitable for entry to the next row of moving blades. Each stage will consist of one rotor row followed by a stator row, but it is usual to provide a row of so called inlet guide vanes. This is an additional stator row upstream of the first stage in the compressor and serves to direct the axially approaching flow correctly into the first row of rotating blades. For a compressor, a row of rotor blades followed by a row of stator blades is called a stage. Two forms of rotor have been taken up, namely drum type and disk type The disk type is used where consideration of low weight is most important. There is a contraction of the flow annulus from the low to the high pressure end of the compressor. This is necessary to maintain the axial velocity at a reasonably constant level throughout the length of the compressor *despite the increase in density of air In an* axial compressor, the flow rate tends to be high and pressure rise per stage is low. It also maintains fairly high efficiency




## Energy exchange between rotor and fluid

The relative motion of the blades to the fluid adds velocity or pressure or both to the fluid as it passes through the rotor. The fluid velocity is increased through the rotor, and the stator converts kinetic energy to pressure energy. Some diffusion also occurs in the rotor in most practical designs.

The increase in velocity of the fluid is primarily in the tangential direction (swirl) and the stator removes this angular momentum.

The pressure rise results in a stagnation temperature rise. For a given geometry the temperature rise depends on the square of the tangential Mach number of the rotor row. Current turbofan engines have fans that operate at Mach 1.7 or more, and require significant containment and noise suppression structures to reduce blade loss damage and noise.

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# Performance characteristics

A nonlinear model is developed to predict the transient response of a compression system subsequent to a perturbation from steady operating conditions. It is found that for the system investigated there is an important non dimensional parameter on which this response depends. Whether this parameter is above or below a critical value determines which mode of compressor instability, rotating stall or surge, will be encountered at the stall line.[4] Representation of the performance characteristics of axial compressor can be done by following parameters:

- Pressure (P)
- $Flow\ Rate\ (Q)$
- Non-dimensional Flow Rate ($\frac{\dot{m}\sqrt{T_{01}}}{p_{01}}$)
- Flow Coefficient ($\phi = \frac{c_m}{U}$)
- Stage Loading Coefficient ($\psi = \frac{V}{U^2}$)

application of Axial flow compressors

***1.Blast furnaces***
***2. Air separation plants***
***3. Fluid catalytic cracking units***
***4. Nitric acid plants***
***5. Jet-engine test facilities***

**Stage load coefficient** : The total enthalpy rise through a rotor blade row is expressed by the well-known Euler turbine equation, i.e.

$$\Delta H = U(c_{\theta 2} - c_{\theta 1})$$

where $\Delta H$ is the total enthalpy rise through the rotor. It is often useful to introduce dimensionless stage performance parameters for a "repeating" stage, i.e. the rotor-inlet (station 1) and the stator-outlet (station 3) from the previous stage has identical velocity diagrams. Then, the stage load coefficient, $\Psi$ can be defined as

$$\psi = \frac{\Delta H}{U^2} = \frac{(c_{\theta 2} - c_{\theta 1})}{U}$$

**Stage flow coefficient :** The stage flow coefficient,$\phi$is defined as followed.

$$\phi = \frac{c_m}{U}$$

This expresses the ratio between the meridional velocity and the blade velocity. A high stage flow coefficient indicated a high flow through the stage relative to the blade velocity. A low whirl velocity change in a stage would also indicate a high stage flow coefficient and vice versa

**Stage reaction** The stage reaction, R, is defined as the fraction of the rise in static enthalpy in rotor compared to the rise in stagnation enthalpy throughout the entire stage.

$$R = \frac{h_2 - h_1}{h_{03} - h_{01}}$$

If a compressor stage would have a stage reaction of 1.0 or 100%, the rotor would do all of the diffusion in the stage. Similar if the stage reaction is 0 than the stator will do all of the diffusion of the working fluid. It is never good to have either a stage reaction of 1.0 or 0. The literature, reference 1, suggest that a stage reaction about 0.5 i.e. the diffusion is equally divided between the two blade rows. But in practice a higher stage reaction is preferred. Increasing the stage reaction results in a decrease in whirl prior to the rotor. A smaller whirl will create a larger relative inlet velocity to the rotor row, at a constant Cp, and hence make it easier for the rotor to increase the static pressure.

# Efficiency

The term efficiency finds very wide application in turbo machinery. For all machines or stages, efficiency is defined as.

$$\eta = \frac{work\ \ into\ ideal\ compressor}{work\ intio\ actual\ compressor}$$

There are several different ways of evaluating efficiency and these reveal different information. Two of the most widely used efficiencies are the isentropic efficiency and the polytropic efficiency.

# Isentropic efficiency

The isentropic efficiency can be expressed as the ratio between enthalpy change in an ideal compressor and the actual enthalpy change. An ideal compressor which is both adiabatic and reversible cannot alter the entropy of the gas flowing through it. These types of compressors are usually referred to as isentropic. Since there will be some losses which generates an entropy rise, the actual work into the compressor will differ from an ideal one. The efficiency can then be described as,

$$\eta_{isen} = \frac{h_{02_s} - h_{01}}{h_{02} - h_{01}}$$

The subscript s denotes entropy held constant. a typical schematic diagram over a reversible adiabatic compression.

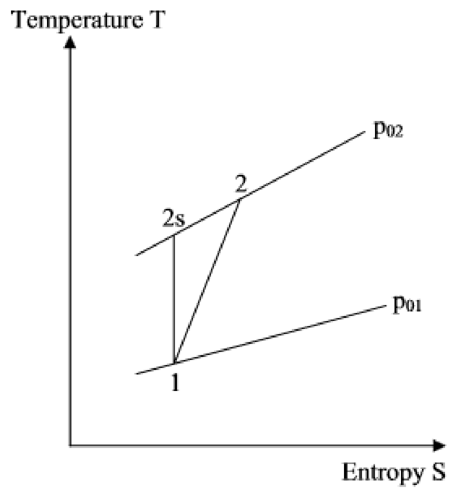


**Figure 2.6**, isentropic compression

$\eta$

The constant pressure lines in the T-S diagram, Figure 2.6, have a slope proportional to the temperature and diverge as the temperature increases. For a given pressure rise the work input needed is greater for the later stages in a compressor, this because the temperature is higher and also that the work input required by the later stages is raised because of the previous stages. The isentropic efficiency therefore gets lower as the overall pressure ratio is increased. To cope with this problem, efficiency the so- called polytrophic or small-stage efficiency may be used instead

# Polytropic efficiency

The definition of polytrophic efficiency is as follows.

$$\eta_{poly} = \frac{dh_s}{dh}$$

*By applying Gibbs law and the relationship between temperature and enthalpy it can be rewritten so it depends on temperatures and pressures instead.*

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$$0 = Tds = dh_s - vdp$$

$$dh = c_p dT$$

$$\eta_{poly} = \frac{vdp}{c_p dT}$$

$$pv = RT$$

$$\eta_{poly} = \frac{R\frac{1}{p}dp}{c_p\frac{1}{T}dT}$$

Integrating the expression on pressure, p leads to the following equation.

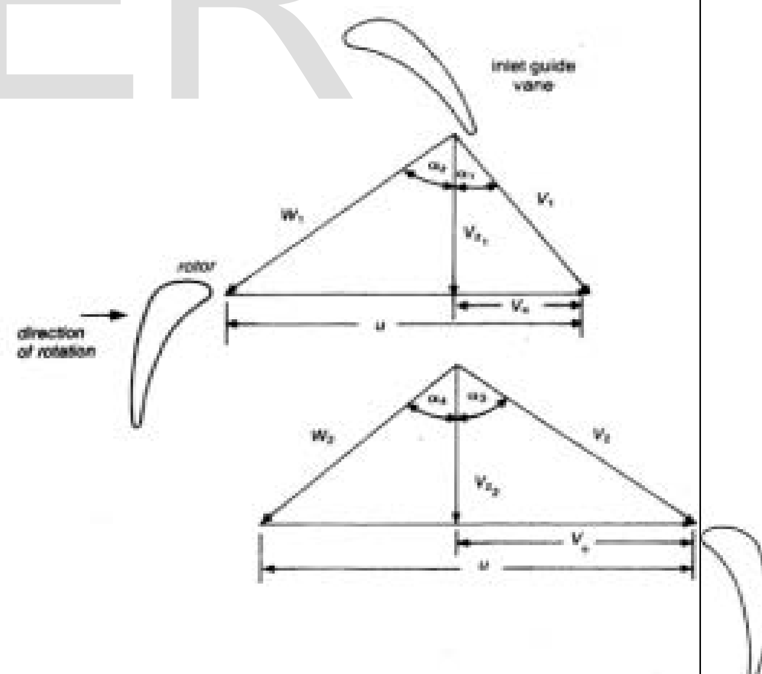
$$\eta_{poly} = \frac{Rln\left(\frac{p_2}{p_1}\right)}{\int_1^2 c_{p(T)\frac{1}{T}dT}}$$

One can also assume that the specific heat capacity is constant, which is not the case in this thesis. If this is assumed, the following expression can be

$$\eta_{poly} = \frac{k-1}{k}\frac{ln\left(\frac{p_2}{p_1}\right)}{ln\left(\frac{T_2}{T_1}\right)}$$

# Velocity triangle

As stated earlier, an axial-flow compressor operates on the principle of putting work into the incoming air by acceleration and diffusion. Air enters the rotor as shown in figure with an absolute velocity (V) and an angle $\alpha_1$, which combines vectorially with the tangential velocity of the blade (U) to produce the resultant relative velocity $w_1$ at an angle $\alpha_2$ Air flowing through the passages formed by the rotor blades is given a relative velocity $w_2$ at an angle $\alpha_4$, which is less than $\alpha_2$ because of the camber of the blades. Note that $w_2$ is less than $w_1$, resulting from an increase in the passage width as the blades becomes thinner toward the trailing edges. Therefore, some diffusion will take place in the rotor section of the stage. The combination of the relative exit velocity and blade velocity produce an absolute velocity $v_2$ at the exit of the rotor. The air then passes through the stator, where it is turned through an angle so that the air is directed into the rotor of the next stage with a minimum incidence angle. The air entering the rotor has an axial component at an absolute velocity $v_{z_1}$ and a tangential component $v_{\theta_1}$




Applying the Euler turbine equation

$$H = \frac{1}{g_c}[U_1V_{\theta1} - U_2V_{\theta2}]$$

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And assuming that the blade speed at the inlet and exit of the compressor are

$$V_{\theta 1} = V_{Z1} \tan \alpha_1$$

$$V_{\theta 2} = V_{Z1} \tan \alpha_3$$

Equation (1) can be written

$$H = \frac{U_1}{g_c}(V_{Z1} \tan \alpha_2 - V_{Z2} \tan \alpha_3)$$

Assuming that the axial component $V_z$ remains unchanged,

$$H = \frac{UV_Z}{g_c}(\tan \alpha_1 - \tan \alpha_3)$$

The previous relationship is it terms of the absolute inlet and outlet velocities angles or the relative air angles , the following relationship is obtained:

$$U_1 - U_2 = V_{Z!} \tan \alpha_1 = V_{z1} \tan \alpha_2 = V_{Z2} \tan \alpha_3 + V_{z2} \tan \alpha_4$$

Therefore,

$$H = \frac{UV_2}{g_c}(\tan \alpha_2 - \tan \alpha_4)$$

Previous relationship can be written to calculate the pressure rise in the stage:

$$c_p T_{in} \left[ \left( \frac{p_2}{p_1} \right)^{\frac{\gamma - 1}{\gamma}} - 1 \right] = \frac{UV_2}{g_c}(\tan \alpha_2 - \tan \alpha_4)$$

Can written as

$$\frac{p_2}{p_1} = \left\{ \frac{UV_2}{g_c c_p T_{in}}[\tan \alpha_2 - \tan \alpha_4] + 1 \right\}^{\frac{\gamma}{\gamma + 1}}$$

# Degree Of Reaction

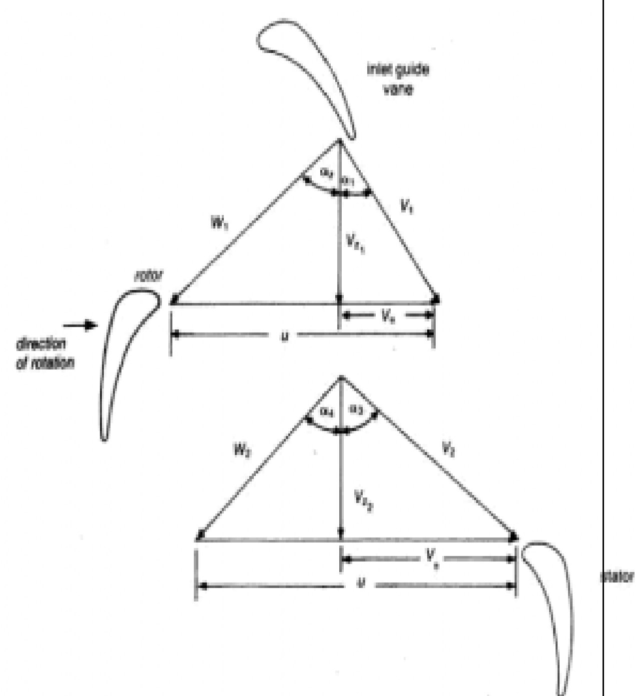
- The degree of reaction in an axial-flow compressor is defined as the *ratio of the change of static head in the rotor to the head generated in the stage:*

$$R = \frac{V_2}{2U}(\tan \alpha_2 + \tan \alpha_4)$$

- In the symmetrical axial-floe stage ,the blades and their orientation in the rotor and stator are reflected image of each other. Thus in a symmetrical axial flow stage where $V_1 = W_2$and $V_2 = W_1$as seen in figure, the head delivered in the velocity as given by

$$H = \frac{1}{2g_c}\left[ (U_1^2 - U_2^2) + (V_1^2 - V_2^2) + (W_2^2 - W_1^2) \right]$$

$$H = \frac{1}{2g_c}[W_2^2 - W_1^2]$$



- *Axial compressors are rotating, aerofoil based compressors in which the working fluid principally flows parallel to the axis of rotation. This is in contrast with centrifugal, axi
- centrifugal and mixed-flow compressors where the air may enter axially but will have a significant radial component on exit. *Axial flow compressors produce a continuous flow of compressed gas, and have the benefits of high efficiencies and large mass flow capacity, particularly in relation to their cross-section. They do, however, require several rows of aerofoils to achieve large pressure rises making them complex and expensive relative to other designs (e.g. centrifugal compressor). *Centrifugal fan/blowers are more suited to continuous-duty applications such as ventilation fans, air movers, cooling units, and other uses that require high volume with little or no pressure increase. In contrast, multi-stage reciprocating compressors often achieve discharge pressures of 8,000 to 10,000 psi (59 MPa to 69MPa). One example of an application of centrifugal compressors is their use in re-injecting natural gas back into oil fields to increase oil production. Centrifugal compressors are often used in small gas turbine engines like APUs (auxiliary power units) and smaller aircraft gas turbines.

- A significant reason for this is that with current technology, the equivalent flow axial compressor will be less efficient due primarily to a combination of rotor and variable stator tip-clearance losses. There are few single stage centrifugal compressors capable of pressure-ratios over 10:1, due to stress considerations which severely limit the compressor's safety, durability and life expectancy.

- Compressor section location depends on the type of compressor. In the centrifugal-flow engine the compressor is between the accessory section and the combustion section; in the axial-flow engine the compressor is between the air inlet duct and the combustion section.
  *Centrifugal-flow compressors have the following advantages:
  * High pressure rise per stage.
  * Efficiency over wide rotational speed range.
  * Simplicity of manufacture with resulting low cost.
  * Low weight.
  * Low starting power requirements.
  They have the following disadvantages:
  * Large frontal area for given airflow.
  * Impracticality if more than two stages because of losses in turns between stages.
  **Axial-flow compressors have the following advantages:
  * High peak efficiency.
  * Small frontal area forgiven airflow.
  * Straight-through flow, allowing high ram efficiency.
  * Increased pressure rise due to

increased number of stages with negligible losses.
They have the following disadvantages:
* Good efficiency over narrow rotational speed range.
* Difficulty of manufacture and high cost.
* Relatively high weight.
* High starting power requirements (this has been partially overcome by split compressors).

## Stalling

Stalling is an important phenomenon that affects the performance of the compressor. An analysis is made of rotating stall in compressors of many stages, finding conditions under which a flow distortion can occur which is steady in a traveling reference frame, even though upstream total and downstream static pressure are constant. In the compressor, a pressure-rise hysteresis is assumed.[6] It is a situation of separation of air flow at the aero-foil blades of the compressor. This phenomenon depending upon the blade-profile leads to reduced compression and drop in engine power. ***Positive Stalling***- Flow separation occur on the suction side of the blade. ***Negative Stalling***- Flow separation occur on the pressure side of the blade. Negative stall is negligible compared to the positive stall because flow separation is least likely to occur on the pressure side of the blade.

### Effects

- This reduces efficiency of the compressor
- Forced vibrations in the blades due to passage through stall compartment.
- These forced vibrations may match with the natural frequency of the blades causing resonance and hence failure of the blade.

## • Compressor maps

- A map shows the performance of a compressor and allows determination of optimal operating conditions. It shows the mass flow along the horizontal axis, typically as a percentage of the design mass flow rate, or in actual units. The pressure rise is indicated on the vertical axis as a ratio between inlet and exit stagnation pressures.
- A surge or stall line identifies the boundary to the left of which the compressor performance rapidly degrades and identifies the maximum pressure ratio that can be achieved for a given mass flow. Contours of efficiency are drawn as well as performance lines for operation at particular rotational speeds.

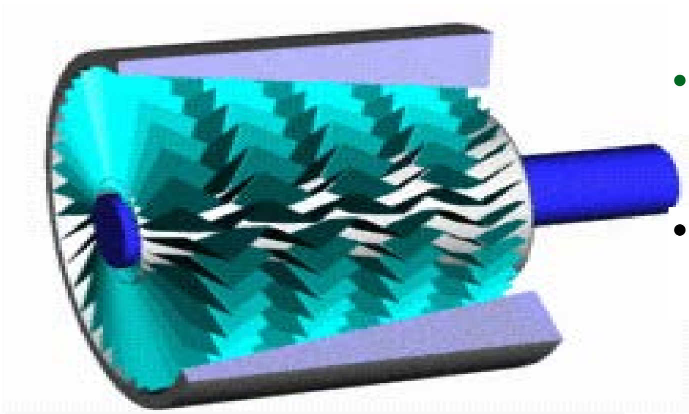
## • Compression stability

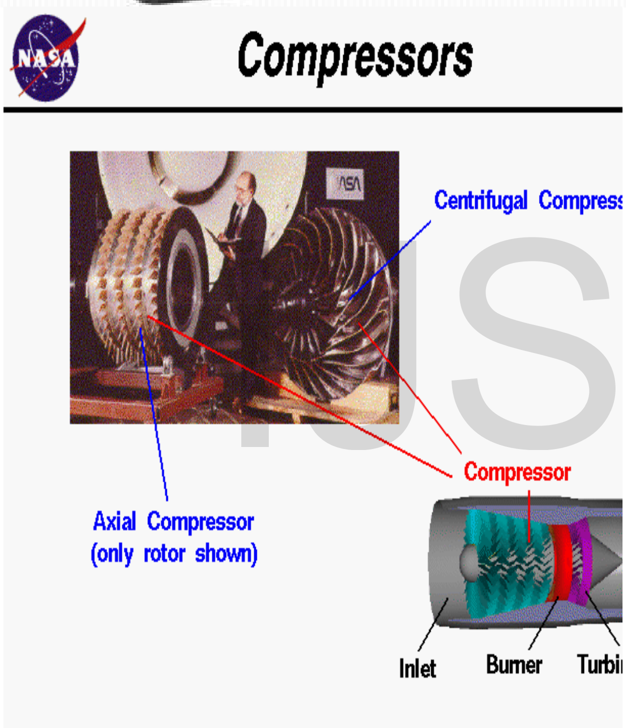
- Operating efficiency is highest close to the stall line. If the downstream pressure is increased beyond the maximum possible the compressor will stall and become unstable.
- Typically the instability will be at the Helmholtz frequency of the system, taking the downstream plenum into account.

Conclusion: The importance of axial flow compressor and the performance parameters of axial flows is discussed and concluded that axial flow compressor is more efficient and so it is used in turbojets when compared with other turbo machinery .

ISSN 2229-5518

# Figures



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